ORIGINAL ARTICLE

Exposure to mercury in the mine of Almadén

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Objectives: To describe the process for obtaining mercury and the historical exposure of Almadén miners to mercury.
Methods: Information on every workplace and historical data on production, technological changes in the productive process and biological and environmental values of mercury was collected. A job-exposure matrix was built with these values and the exposure to inorganic mercury was estimated quantitatively as µg/l of urine mercury. A cumulative exposure index was calculated for every worker by adding the estimates for every year in the different workplaces.
Results: In the mine, the highest exposures occurred during drilling, with values up to 2.26 mg/m^3 in air, 2194 µg/l in urine and 374 µg/l in blood. Furnace operation and cleaning were the tasks with the highest values in metallurgy, peaking up to 3.37 mg/m^3. The filling of bottles with mercury by free fall gave values within a range of 1.13–2.43 mg/m^3 in air; these values dropped to 0.32–0.83 mg/m^3 after introducing a new ventilation system. The toxicity effects of high doses of inorganic mercury on the central nervous and urinary systems have been known for decades.
Conclusions: The exposure of the workers in Almadén mines to mercury has been very high. The extremely high content cinnabar ore of the mine explains the increased concentrations of mercury in air at the work places. This, together with inadequate working conditions, explains the high mercury levels found in blood and urine during the study period.

They penetrated to the bowels of earth and dug up wealth, bad cause of all our ills, rich ores which long ago the earth had hid and deep removed to gloomy Stygian caves.Metamorphoses, Ovidius

The mercury deposits of Almadén (Spain) have the greatest concentration of this liquid metal on Earth. Its production since historical times has been estimated in approximately 250 000 MT of metal, which represents about one-third of the total mercury used-up by mankind throughout history.[1] The exploitation of cinnabar deposits, the main mercury ore, dates back to very remote times. The Romans were the first to extract mercury systematically, using it mostly as a pigment. The main evidence of Roman use of mercury are the great number of coins, medals, vessels and other historical objects found in the Almadenejos and Valdeazogues areas.[2] On the basis of these data, we can ascertain that the Almadén mines are >2000-years old, and the oldest known in the world.[3] In 714, the Arabs invaded Iberia and the mines were passed on to the Caliphs' government. They greatly influenced the process for obtaining mercury, as shown by the marks left after their departure: Al-mahden, which means mine, and azogue (mercury), a term used only in Spain and South America, are words of Arabic origin.

Mercury became important in the modern world due to its wide use in amalgamation processes. Around AD1550, Bartolomé de Medina developed a technique that improved or benefited silver minerals through amalgamation with mercury. This new metallurgic process, known as yard benefit, represented a significant improvement compared with the traditional melting process in furnaces, used in the silver mines of Spanish America. The lower cost, the possibility of exploiting low-content deposits, the reduction in fuel requirements and the difficulty in obtaining mercury in the mountains where the mines were located were some of the advantages that contributed to the rapid extension of this method to the mines of New Spain (present day Mexico) and, later, to Peru. Melting was not completely abandoned, but amalgamation became the most widely used metallurgical technique. This caused a dramatic increase in the demand for mercury.[1] The independence of the Spanish colonies and the introduction of mercury from California into the world market, which had been monopolised by Almadén, led to a reduction in production costs. A group of engineers promoted a large reorganisation of the mine,[4–6] which is of interest for us, as it implied a reduction in the levels of exposure to mercury, deriving from new working guidelines. This, together with additional technological changes and hygiene improvements, allowed a significant reduction in the risk levels throughout the production process.

Currently, the mines at Almadén belong to the Spanish Government. Production of mercury has decreased notably with time (fig 1), and the number of workers assigned to mineral extraction and production has also decreased. Mining activity ceased in 2001, with a total of 7644 tons of mineral extracted in the past decade. The metallurgical activity ended in 2004.

Almadén deposits have been, and still are, extremely rich, with a mercury content of around 8%, much higher than any other mercury mine. The mine of Abbadia San Salvatore, in Monte Amiata, Italy,[7] had a cinnabar content of between 0.6% and 2%. In Idrija, Slovenia,[8] this value ranged from 1.5% to 3.2%. In Almadén, small drops of native mercury can be observed embedded in the cinnabar walls in most of the mines. The deposits are vertically oriented, the width growing with depth. This has led to the increasing deepening of the mine throughout history, with most of the excavations made in useful mineral due to the width of the metal veins. All this, together with mercury's physical and chemical properties, vapour emission at ambient temperatures (vapour pressure 0.17 Pa) and the deficiencies in the ventilation of the inner area of the mines, had a great effect on the mortality and morbidity of miners throughout the years, which is well described in the

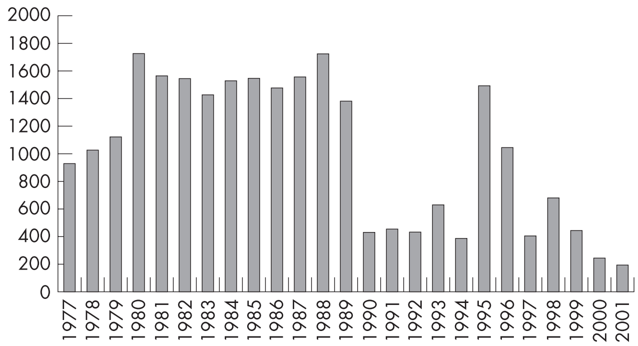

Figure 1 Annual mercury production (tons) in Almadén mines.

literature since the 16th century.[9–14] Today, the occupational exposure to mercury is still important, since it is used in several industries.[15] Environmental exposure is also important, mostly from food and dental amalgams; as mercury is very persistent in the environment, it may be a long-term risk for any exposed populations.[16]

The aim of this paper is to describe the process of obtaining mercury and the historical exposure of the Almadén miners to mercury, and to discuss the methodological problems raised in the evaluation of the occupational exposure. Data were obtained for a cohort study on the mortality of mercury miners in Almadén, which has been included in a multicentre cohort study, coordinated by the International Agency for Research on Cancer, designed to evaluate the possible carcinogenic risk associated with the exposure to inorganic mercury.[17] The description of the Spanish cohort and the methodological problems involved in its definition have been reported previously.[18]

METHODS

The cohort was built in 1950 from the records of personnel of Minas de Almadén y Arrayanes S*A*. Workers joining the mine in the following years until the end of the follow-up period in 1994 were also included.

The process of mercury extraction and metallurgy was reconstructed by a team that included an industrial hygienist from the public control office, with wide experience in the evaluation of working conditions in the mine, and the mine prevention staff. Data on mercury production, technological changes in the productive process and every work place were collected. Workers were classified according to the time since first exposure, exposure calendar date and the total length of exposure.

All the historical records on biological and environmental exposure levels from the mine were obtained from the mine medical services and the labour authority office (Centro de Seguridad e Higiene en el Trabajo de Ciudad Real). Mercury vapour in workplaces was measured by an active sampling device using hopcalite as the solid sorbent.[19–22] A defined volume of air was passed through a small glass tube filled with hopcalite with battery-operated pumps, with about 0.2 l/min flow rate. The sampling time was around two-thirds of the work shift. The tubes were carefully sealed in plastic containers before and after they were used. The mercury in the sample was analysed using a cold vapour-atomic absorption spectrophotometer. A volume of 20 ml blood and 100 ml urine samples were taken from workers from workplaces that were representative of the respective group, at the end of the working week. Since 1980, urine was collected in metal-free, sterile plastic containers. The total concentration of mercury in air, blood and urine was measured by cold vapour-atomic absorption, which included $SnCl_2$. Urine mercury concentrations were not corrected either by specific gravity or by creatinine. The quality of the analysis was controlled using control samples in every series and with the participation of the laboratory in an external quality-control programme of mercury analysis organised by the Centre de Toxicologie du Québec (Laval University, Québec city, Québec, Canada).[23–27]

A job-exposure matrix was built based on the available biological indicators of mercury in blood and urine, on the reconstruction of the technological process and on the hygienic conditions in the different periods. Exposure of a given job and period (supervisor, 1985–6) was used as reference. The rest of the values were quantified in relative units to this standard; thus, a value of two implies an exposure double than the standard job-period.

The exposure to inorganic mercury was quantified as µg/l of urine mercury. An accumulated exposure index was built for every worker by adding the estimations made for every working year at different working places.

Process used to obtain mercury

The production process included two main stages. The first one occurred completely underground and was aimed at obtaining useful mineral: cinnabar (mercury sulphide). It included all steps from the excavation of the deposits to the mineral transport to the surface, known as zafra, as well as all the

New reinforcement ↓ (between 1960–71 and 1972–82); H_2O ↓ (between <1960 and 1960–71); Inverted craters ↓ (between 1983–84 and 1985–86)

	<1960	1960–71	1972–82	1983–84	1985–86
Driller	>30	30	25	10	15
Builder	30	30	10	10	10
Timberman	30	30	10	10	10
Rubbish carrier	15	15	15	15	15
Shoveller	Non-existing	15	15	15	10
Maintenance	10	10	4	4	4
Blaster	4	4	2	2	1
Supervisor	2	2	1	1	1
Various labourers	1/2	1/2	1/2	1/2	1/2

Figure 2 Almadén mine's job-exposure matrix.

maintenance and preservation tasks of the underground production area. Five tasks could be identified in this stage: excavation, extraction, fortification, drainage and ventilation. Since the end of the 19th century, all underground work was organised in two 6 h periods (2 days) per week, one working day followed by two rest days, which meant eight pay periods (working days) per month, with 48 working hours. Drilling with water was introduced in 1960, the ventilation system was improved in the 70's and, in the mid-80's, a new extraction technology (inverted crater systems) was applied in the mid-80's. All these measures led to a progressive reduction in the exposure to mercury in the second half of the 20th century. According to the working-place characteristics in the underground mine, three different periods have been identified along the study interval, 1950–94: traditional system before 1972; traditional system between 1972 and 1985; new system since 1985.

Changes from the first to the second system were due to the introduction of technological improvements that modified working conditions, mostly forced ventilation, improvement of the ventilation circuit, and mechanisation of mineral loading and manipulation, which had been done manually before 1972. The exploitation system changed radically from the second traditional system to the new one, with the disappearance of most of the previous working places. Table 1 provides a detailed list of the working places, which helps to understand the nature of the changes.

The second stage of the process (milling or metallurgy) included mineral distillation, mercury packaging and storage. It comprised three main tasks: mineral preparation or breakdown, mineral distillation in furnace through the burning or cooking of the cinnabar, and the condensation of the resulting mercury vapour. In 1952 new Cincinnati furnaces were installed, replacing the old Spirek furnaces, which reduced the mercury exposure. In the last few years, Pacific furnaces were installed. Finally, the resulting mercury was packed and stored. The process was completed with laboratory work and in the plants of mercury-derived products, oxides and salts, mostly. Table 2 describes the working places.

RESULTS

Table 1 and 2 provides a detailed list of the working places in the underground mine and the working places in the non-mining stages. To complete this description, we must emphasise that workers rotations among the different work-places were unsual, and the use of personal protection devices was sporadic until the last years of the considered period.

Throughout the studied period (1950–94), a total of 3648 miners were followed-up and it contributed 103 728 person-years to the cohort study. Table 3 shows the mercury values in air, blood and urine at different work places and periods. We only have biological data for 795 workers.

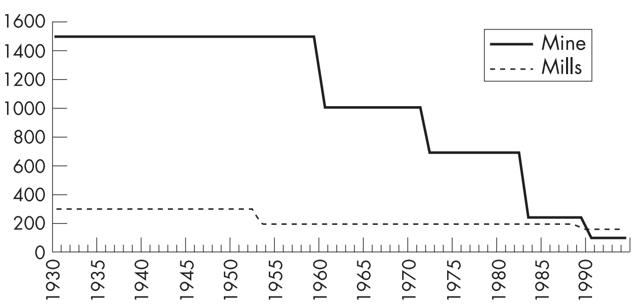

Figure 3 Estimated urinary mercury levels (μg/l) by year mine–mills of Almadén.

Using these levels and the reconstruction of the technological process and hygienic conditions throughout the study period, the job-exposure matrix shown in fig 2 was built. Figure 3 gives the quantification of the exposure values, measured as μg/l of mercury in urine. An accumulated exposure index was calculated for every worker by adding the estimates for every working year in the different working places.

The workers were also exposed to crystalline silica, in both mining and milling stages. Measurements with personal devices of dust in the mills during the late 70's show levels around 5 mg/m^3 (total dust) with a 10% content of free silica. There are no measurements of radon, asbestos, arsenic or diesel emissions inside the mine.

DISCUSSION

The data included in this study constitute an effort to describe systematically describe the available evidence on exposure to mercury in mines. Previously, these had been addressed in partial and disperse studies. The quantitative exposure data show some gaps for certain work places and periods. The analysis of mercury in urine started in 1970 (uncorrected and without systematic samples); before this, the only preventive measure was medical surveillance of the exposed workers. Blood mercury analysis started in 1972, and was considered as the main exposure-control method. Urine was analysed to obtain additional information on excretion rates. Airborne and biological exposure data were obtained by sampling different work places and miners—that is, not all the miners and work places were analysed. So, the number of workers with analytical data are a subsample of 795 workers of the cohort.

This lack of complete exposure records do not allow for the quantitative evaluation of the exposure for every job and period. However, a multidisciplinary team that included an industrial hygienist from the labour authority office, with wide experience in the evaluation of working conditions in the mine, and the mine prevention staff, made the reconstruction of data on mercury production, technological changes and exposure to mercury possible. This led to a semiquantitative assessment of the exposure levels in relative units. The results for different jobs and periods are shown in fig 2, which is one of the few estimates of mercury exposure in mines available in the literature.

Table 3 gives the exposure of the Almadén workers to mercury, which was very high. The very high concentration of the mineral explains the high concentration of airborne mercury in all the work places, which, together with the inadequate working conditions, led to the high levels detected in urine and blood. Personal protection devices were available then, but their use was scarce and inappropriate. In the mine, the highest exposures occurred during drilling and during the work in the galleries after the blast. This explains the high values found for drillers, builders, timbermen, blasters, rubbish carriers and shovellers, with air values up to 2.26 mg/m^3, 2194 μg/l in urine and 374 μg/l in blood. Paradoxically, the introduction of the new system in 1985, with relevant environmental protection measurements, did not result in a significant improvement. This can be explained by the fact that the improvements were applied in a new exploitation, but not in the old mine where the old ventilation systems and galleries coexisted.

The only relevant change to the milling process occurred in 1952, when the new Cincinnati furnaces substituted the old Spirek furnaces. Thus, the mineral milling values given in table 3 can be considered as representative for the whole period since 1952. As expected, the furnace operation and its cleaning were the tasks with the highest mercury values, with peaks up to 3.37 mg/m^3, similar to those found in the mine of Abbadía

Table 1 Description of the working places in the mine stage

Traditional system; before 1972	Interior mine, traditional system, after 1972	Interior mine, new system (inverted craters), since 1985
Driller: the underground work was organised in two 6 h periods (2 days) week, one working day followed by, two rest days, which meant eight wages per month, with 48 working hours. Drilling at the mineral face, using compressed air hammer, with water supply since1960. The shaft structure was wooden and very scarce ventilation to surface.	Driller: day down mine, 48 h/month. Drilling at the mineral face for extraction. Drilling in lateral walls and roof to enable reinforcement, using bolts. The ventilation improves owing to greater number of ventilation shafts, and the draught sweeps across the extraction face.	Driller: drills the mineral and dead to fortify the cross ways and the chambers. The chambers are open and the ventilation conditions are better than in the traditional system. No mineral is removed, nor are any explosions carried out.
Drillers assistant: aids the driller with his work. He cleans the driller's face, helps to make the openings, takes care of the air and water supply and transports the bits.	Driller's assistant: as before 1972, but with improved environmental and safety conditions.	Driller's assistant: carries out the traditional tasks involved in assisting the driller, in the new chambers.
Interior worker: takes charge of moving the mineral thrown back by the outstope, and pours it into the winze, which in turn serves as the entrance for air into the chamber. He uses hand tools for his work.	Interior worker: the work previously carried out disappears, being substituted by the shoveller and his assistant.	Jumbo operator: carries out the drilling of the chambers and cross ways, using a mechanical truck with a water injection hydraulic drilling system, which allows a distance from the face.
Builder, assistant builder, builders labourer: transport and distribute the gobbing that falls through the winze, and widen and reinforce the lower winze as the operation ascends.	Shoveller and assistant: withdraw the mineral using a power shovel, and throw it into the hopper, through the winze. Spread out the gobbing in the extraction chamber. Carry out the fundamental work of the builder, in the chamber, this work being carried out also by the shovellers.	Jumbo operator's assistant: helps the operator in the different manoeuvres. He cleans and prepares the face for its opening.
Timberman and assistant: reinforce the lateral walls of the exploitation using wood. In the extraction chamber, take the measurements and prepare the walls in the principal transport gallery. Works only part-time in the chamber (50–60%).	Builder: the fundamental work of the builder in the chamber disappears, this work also being carried out by the shovellers.	Drill man: uses a rotary drilling machine to make the passages required for communication between chambers at different levels. He uses the wet process, and no mineral removal or explosions are carried out.
Rubbish carrier/carter: collects the rubbish thrown out of the chamber by the labourers and, using hand tools, loads the wagons and take them to the entrance to the gallery shaft.	Timberman and assistant: tasks in the chamber disappear, as metal reinforcement is now used.	Shoveller: controls the diesel power shovel loader, which is more powerful and of greater capacity than the pneumatic loader in the traditional system. He loads the mineral into the dumper trucks, or transports it directly to the grate of the hopper, from where it continues on to the crusher.
Blaster/ordnance engineer: preparing, placing and blowing-up of explosives in different chambers. Works part-time in the chambers, when no work is being carried out in them.	Rubbish carrier/carter: loads and transports the waggons. Loading is carried out with a pneumatically closed hopper, and transportation with a locomotive.	Dumper driver: is in charge of the dumper, and transports the mineral from the chamber and/or cross ways to the grate of the hopper, from where it continues on to the crusher.
Various labourers: carry out various tasks, relating to clearing and transportation of diverse materials, in the general gallery.	Mechanic and assistant: carries out the maintenance of the hammers, shovels and the ventilation and compressed air installations.	Grate operator: assists in the operation of unloading the dumpers and the shover, and breaks up the larger blocks with a hammer.
Pump operator and assistant: control of water-pumping system in the general gallery and drains water accumulated in the miner.	The working places blaster, various labourer, pump operator and assistant, track-engineer, signaler loader, minder, supervisor, engineer and assistant engineer are the same as in the previous period.	Crusher operator: controls the operation of the crusher and its supply. He frequently has to unblock the machine using levers and hammers. He works inside the mine.
Track-engineer: installation and maintenance of transport tracks in the general gallery.		Belt operator: controls the operation of the conveyor belt, and takes care of clearing the gallery. The belt receives the mineral that comes from the crusher and carries it to the shaft, from where it is taken outside.
Signaller loader: carries out the operations of loading and unloading the cages in the shaft zone. Works full-time in the general gallery/shaft.		
Minder: carries out shaft maintenance, checking and repairing and deterioration produced.		
Assistant mechanic: maintenance of the hammers of the different drillers. Spends part of the working day in the general gallery, and the rest in the chambers.		
Supervisor: oversees the tasks relating to preparation, winning and transport. He spends part of the day working in the general gallery and the rest in the chambers.		
Engineer and assistant engineer: management and supervision of the distinct tasks carried out in the interior of the mine. Spend part of the day working down the mine and part outside.		

Table 2 Description of the working places in the non-mining stages

Metallurgy

Crusher operator: works daily, 36 h/week. Worker in charge of the crusher and mills. The crusher is located in an underground transport gallery, which is connected to the actual metallurgy section. The mills are above ground

Driver: works on alternate days, 18 h/week. In charge of taking the mineral, using mechanical transporters, to the initial hoppers of the furnaces

Elevation worker: works on alternate working days. Driver's assistant who carries out tasks relating to the control of conveyor belt, the distribution trucks and cleaning. Remains in the furnace building

Plant mechanic: alternate working days. Formerly calciner. In charge of furnace operation. Remains in the furnace building

Cinder worker: works on alternate working days. In charge of the removal of the slag. Loads the slag lorries from the hoppers. Before 1970, he loaded the wagons and had to push them with the slag still hot. Works mostly outside

Tray operator: until 1980. Works on alternate working days. Controls the supply to the furnace. Extends the mineral on the first tray, where the heating process begins

Soot transporter: works on alternate working days. Removes the mercury and soot from the distillation batteries by means of a container, which takes it along an underground gallery to the soot-processing plant

Soot worker: works daily. Carries out the tasks of filtration, beating and separation of the mercury from the other impurities, for its subsequent transfer to the mercury store

Furnace cleaner: alternate working days. In charge of cleaning the furnace and distillation areas

Section worker: works daily. General clearing of the metallurgic section or area and various tasks to aid the rest of the department. Help the shoveller remove dust from the cyclone separator

Maintenance officer: works daily. Maintenance, revision and repair in general of any machine in the metallurgic section (furnaces, distillation, and so on)

Shoveller: works daily. Movement of materials in the section. Extracts and removes the dust accumulated in the cyclone separator

Supervisor: works on alternate working days. Supervision of the different tasks of the department. Spends the working day in the following sections: furnaces, distillation, processing and so on

Water treatment plant operator: works daily. Controls the operation of the treatment plant. Works in the open air
Engineers and technical engineers: works daily. Manages and supervises the running of the department

Filling

Mercury store worker: works daily. In charge of filling the bottles with mercury by free fall. No adequate ventilation until 1989. Cleans ventilated bottles. Prepares the packaging and seals. Cleans the store

Store supervisor: works daily. Supervision of all the tasks to be carried out in the mercury store

By-products

Red oxide plant operator: supply to the furnaces ($Hg\text{-}NO_3H$), removes from the furnaces (red oxide). Filling bags and packaging. Parameters process control. Plant cleaning and gas washing control

Salts plant operator: the plant produces $ClHg_2$, yellow oxide, $Hg_2\,Cl_2$, $Cl\,Hg\,NH_2$. Supply and removal to/from the chambers, going into them with personal devices. Supplies baths and precipitates filter. Products filling and packaging

Laboratory

Quality control and research of new applications and by-products. Mineral sampling and richness quantification

San Salvatore.[7] Finally, high airborne values and corresponding blood and urine values were also found in the free-fall bottle filling, made daily and without an efficient ventilation system until 1985.

The comparison with other mercury mines is not easy, since, as previously said, there are few papers describing the exposure of mercury miners in detail, and there the exposures are for a very limited period of time.[7, 8, 23, 28, 29] The most consistent comparison can be made against the quantitative estimation of exposure to inorganic mercury, measured as μg/l of urine mercury, made for the international multicentric cohort study, coordinated by the International Agency for Research on Cancer.[17] Almadén shows higher mercury levels in air than Idrija (Slovenia) during mineral extraction in all the periods considered, from 1930 to 1994. This information is not available for the Abbadía San Salvatore (Italy) and Nikitovka (Ukraine) mines. However, the milling values are lower in Almaden than in the other three mines. In 1970 the production ceased in mines and mills in Idrija, restarting with minimum production in 1983. This explains the reported decrease in Idirija, to values lower than those in Almadén. In Abbadia San Salvatore, the production of metallic mercury occurred from 1893 to 1976, when mineral extraction was interrupted. Mercury production continued from secondary sources, such as waste muds and all activities ceased in 1983, with the subsequent decrease in the values for this mine.

As mentioned in the introduction, the occupational exposure to mercury is still important in many industries and the environmental exposure is not negligible. In this paper, we provide a risk assessment, and workplace exposure data for mercury during primary extraction. The data confirm that mercury miners are the occupational groups with the highest exposure in work places, reaching peak values during extraction and milling, especially for the driller, builder, timberman, rubbish carrier, shoveller, furnace worker and furnace cleaner. Retrospective data on the exposure of mercury miners provided in this paper are difficult to obtain and scarce in the scientific literature. They can be useful in several active mercury mines in

Table 3 Values of exposure to mercury by job and historical period

		Air mercury (mg/m^3)				Mercury in urine (µg/l)				Mercury in blood (µg/l)			
	Period	n*	Mean	(SD)	Range	n*	Mean	(SD)	Range	n*	Mean	(SD)	Range
Driller	1972–82	7	1.05	(0.33)	0.66 to 1.6	335	797	(483.12)	143 to 2107	335	136.8	(59.3)	34.3 to 287.5
	1983–4	16	0.53	(0.53)	0.04 to 1.66	195	276.8	(212.68)	60 to 1000	195	57.54	(41.07)	12 to 232
	1985–6	6	0.73	(0.31)	0.34 to 1.12	14	324.88	(171.85)	110 to 683	14	94.12	(63.45)	18 to 238
Driller's assistant	1972–82	3	0.83	(0.11)	0.73 to 0.94	–	–	–	–	–	–	–	–
	1983–84	6	0.45	(0.42)	0.055 to 0.94	–	–	–	–	–	–	–	–
	1985–86	1	0.42	–	–	–	–	–	–	–	–	–	–
Interior worker	1972–84	10	0.11	(0.08)	0.01 to 0.27	12	57.83	(27.53)	15 to 124	10	4.47	(2.65)	1.6 to 9.1
Builder	1980–85	–	–	–	–	37	209	(135)	47 to 650	37	54.6	(46.9)	10.9 to 293.2
Timberman	1980–85	–	–	–	–	38	290	(209)	23 to 890	38	82.5	(84.8)	11.1 to 374.3
Blaster	1980–85	–	–	–	–	59	299.39	(216.59)	70 to 979	60	52.68	(33.97)	12 to 159
Rubbish carrier	1972–86	7	1.21	(0.54)	0.01 to 1.57	–	–	–	–	–	–	–	–
Shoveller and assistant	1972–84	12	0.37	(0.60)	0.03 to 2.26	32	649	(490)	142 to 2,194	32	110.5	(49.1)	36.6 to 225.4
	1985–6	9	0.49	(0.33)	0.07 to 1.06	4	74	(16.63)	60 to 98	4	3.8	(2.18)	2.2 to 7
Pump operator and assistant, signaller/ loader, minder, various labourers	1980–5	7	0.01	(0.02)	0.0 to 0.06	24	76	(49)	11 to 254	24	31.2	(10.2)	13.2 to 48.3
Supervisor	1980–5	2	0.03	0	0.03 to 0.03	3	48	–	32 to 65	3	14.6	–	10 to 18
Crusher operator	1981–6	28	0.94	(0.83)	0.05 to 2.72	6	145.8	–	50 to 285	6	46	–	28 to 66
Crusher	1985–6	37	0.92	(0.83)	0.03 to 2.51	–	–	–	–	–	–	–	–
Furnace operator	1985–6	24	1.22	(0.59)	0.37 to 3.09	3	233.33	(82.21)	140 to 295	3	96.67	(20.23)	84 to 120
Furnace cleaner	1985–6	13	1.12	(0.83)	0.40 to 3.18	6	613.5	(178.36)	351 to 840	6	101.17	(43.4)	51 to 169
Soot transporter	1985–6	41	0.84	(0.49)	0.11 to 2.06	3	256	(78.08)	180 to 336	3	35.33	(6.81)	30 to 43
Cinder worker	1985–6	10	0.66	(0.52)	0.16 to 1.94	–	–	–	–	–	–	–	–
Elevation worker	1985–6	31	1.16	(0.74)	0.19 to 3.37	–	–	–	–	–	–	–	–
Maintenance officer	1985–6	5	0.78	(0.17)	0.58 to 0.9	5	197.2	(129.68)	44 to 328	5	80.2	(18.05)	53 to 99
Supervisor	1985–6	12	1.19	(0.54)	0.12 to 2.08	5	487	(208.8)	113 to 866	5	121.8	(79.71)	13 to 192
Mercury store worker	1980–4	8	1.75	(0.49)	1.13 to 2.43	–	–	–	–	–	–	–	–
	1985	5	0.59	(0.21)	0.32 to 0.83	5	431.8	(169.25)	268 to 695	5	96.8	(34.87)	73 to 158
Store supervisor	1980–4	2	1.25	(0.21)	1.1 to 1.39	–	–	–	–	–	–	–	–
	1985	1	1.25	–	–	1	160	–	–	1	97	–	–
Red oxide	1980–4	18	0.32	(0.2)	0.11 to 0.87	8	272.75	(109.93)	137 to 425	8	71.63	(15.47)	56 to 105
Salts	1980–4	14	0.17	(0.14)	0.01 to 0.46	–	–	–	–	–	–	–	–

*Number of samples (people) in the period.
– No available values.

USA, China, Ukraine, etc, since they are essential for correlating levels of mercury exposure and mortality for different causes.

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